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Rural household livelihood change, fuelwood substitution, and hilly ecosystem restoration: Evidence from China

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ABSTRACT

This paper systematically analyzes the driving forces and mechanism of fuelwood substitution and related ecological consequences in an under-developed county in rural Southeast China. Based on 358 respondents from rural households in Changting County, as well as additional statistical data, we present strong evidence in support of the argument that changes in the livelihoods of rural households lead to fuelwood substitution and finally, hilly ecosystem restoration. Important factors influencing fuelwood substitution are closely linked with changes in rural livelihoods: off-farm employment and agricultural specialization. Therefore, these changes are argued to be the primary driving force of fuelwood substitution. Reasons include the increasing opportunity costs of fuelwood collection, increases in household income, and decreases in household energy consumption for cooking, feeding and heating. Such changes have unexpectedly caused significant progress in hilly ecosystem restoration, particularly in mitigation of soil erosion and forest degradation. Thus, it is suggested that the progressive change and improvement in the livelihoods of rural households should be included in the mix of policies intended to restore hilly ecosystems.

Contents

1. Introduction

In China, as in most developing countries, fuelwood gathered from forested commons is an important source of household energy in rural areas [1–4]. It has been estimated that about two thirds of rural households rely directly on traditional biomass fuels (fuelwood, crop residues and dung) for their cooking and heating applications. It is reported that biomass energy (mainly fuelwood) consumption accounts for more than half of total energy use in rural China [1]. Heavy reliance on fuelwood in rural areas of developing countries has resulted in widespread degradation of hilly ecosystems, as well as other environmental problems [5–10]. Substitution

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of fuelwood for alternative fuels can reduce pressure on forests as alternative sources of rural domestic energy (biogas, coal, Liquefied Petroleum Gas (LPG), electricity, solar energy) would not cause forest degradation [11,12]. Therefore, the switch from fuelwood to alternative energy may have great ecological significance.

Evidence indicates that many rural areas in China are substituting drastic amounts of their cooking energy from primary fuelwood and crop residues to modern fuel types such as coal, LPG, electricity, solar energy and biogas [1,13–15]. Moreover, the pace of fuelwood substitution has been faster in over the past decade, and substantially mitigates human disturbance of forestland, as well as promotes the restoration of degraded forestland in many tropical areas of China [16,17]. However, a majority of current research, based primarily on aggregated statistical data, claims that fuelwood substitution induced by economic development has been extremely slow in rural China, hardly producing any positive ecological consequences on forestland [18–21]. China's regional disparities in rural energy consumption and ecosystems are the main reasons for the above research. Given the significant effect of fuelwood substitution on the environment of ecologically fragile regions in Southeastern China, a more detailed investigation of fuelwood substitution would clarify the impact of fuelwood substitution on hilly ecosystems in environmentally fragile areas.

Rural energy use is changing rapidly in China, but the driving forces behind fuelwood substitution are not clear. While the literature based on energy supply and demand have reached some consensus, important questions remain. Studies tended to agree that increasing incomes and better accessibility of alternative fuels in rural areas were the two crucial factors of fuelwood substitution [22–30]. Some recent studies concluded that the rapid increase of rural off-farm employment should play an important role in the rural energy transition from fuelwood to commercial fuels [31–33]. It was also argued that household size and livestock (*e.g.* pig) numbers would have negative impacts on fuelwood substitution [34–37], and a higher education was often considered to encourage fuelwood substitution [38–40]. Policies such as governments' subsidies for biogas or commercial fuels were also believed to promote fuelwood substitution in many poor and environmentally fragile rural regions [2,41,42]. In addition, the increasing opportunity costs of fuelwood collection and changes in traditional preferences were thought to be crucial factors in a household's choice of fuel source [43–45].

Discrete choice regression estimation was also used to explore individual factors on fuel choice by controlling other factors [1]. However, this kind of analysis cannot provide a dynamic understanding of fuelwood substitution, and neglects the interrelation between these factors and the integration of rural fuelwood substitution with farmers' livelihood transition. In fact, the determinants of fuel switching were interactional and were all closely linked with farmers' livelihood change. For example, off-farm employment and agricultural specialization contribute to rising household incomes, large-scale and specialized livestock farms, and higher opportunity costs of fuelwood collection. Therefore, changes in the livelihoods of rural households are the fundamental cause of rural fuelwood substitution. Single determinant of energy consumption such as income, amount of cropland, household size, and education level of householder, livestock numbers, and biogas utilization could be a cause or an effect of changes in the livelihood or rural households [46].

The rapid growth of rural township and village enterprises (TVEs) in the 1980s and private enterprises (PEs) since the 1990s created great demand for manufacturing labor forces. Both TVEs and PEs absorbed a huge number of rural labors. According to the recent sixth population census carried out by the State Statistical Bureau of China in 2011, total peasant workers (*nongmingong*) amounted to more than 242 million in 2010, a great increase from only 153 million rural labors in 2000. They primarily migrated to other towns and cities (accounting for 63.22% of total off-farm rural labors), but about 89 million rural labors were working in local villages and towns. Moreover, it is believed that rural–urban migration will accelerate even more in the near future. On the other hand, agricultural specialization has occurred rapidly in recent years, accompanied with increasing rural off-farm employment, rapid loss of agricultural land, and popularization of advanced agricultural technology [47]. The characteristics of agricultural specialization usually include scale management and mechanization. Traditional subsistence agriculture in China is being transformed into more modern, market-oriented agriculture [48–50].

The main objective of this study is to analyze the impacts of changes in rural livelihoods on household fuelwood substitution and to examine the consequences of fuelwood substitution on hilly ecosystem restoration. Of particular interest is to link the driving forces of fuelwood substitution with changes in rural household livelihoods. To reach this objective, a conceptual model was put forward and a comprehensive analysis was carried out based on an original household survey in Changting County, China. In addition, it must be noted that the alternatives to fuelwood should have the same energy services as fuelwood, mainly to include cooking, livestock breeding, and heating applications.

The organization of the rest of the paper is as follows: Section 2 briefly sets up a conceptual model linking rural fuelwood substitution with changes in household livelihoods, and describes the study area and data collection. Section 3 presents and interprets the results of the study. Section 4 summarizes the major conclusions and discusses policy implications.

2. Methodology

2.1. Conceptual framework

Before proceeding to the empirical analysis, we conceptualized fuelwood substitution within farmers' household livelihoods and hilly ecological restoration in Fig. 1. It was hypothesized that off-farm employment would exert positive effects on rural household fuelwood substitution as off-farm employment tended to result in labor scarcity, higher opportunity costs of fuelwood collection, decreasing household size, and centralization of raising livestock. In addition, the migration of rural populations would lead to labor scarcity in rural areas, leading to rapidly increasing wages. Lastly, off-farm employment, particularly that leading to rural–urban migration, would reduce household size in rural areas, as well as livestock numbers (such as pigs, chickens, and ducks), greatly reducing energy consumption for cooking and feeding applications.

Over the past 30 years, China has been experienced a drastic change toward large scale farming, incorporating land lease markets and technological dissemination, leading to specialization in agricultural production [50]. Specialized agriculture generally has higher labor productivity due to economies of scale. An increase in agricultural specialization provides a boost to the labor market and further propels the average wage of rural workers and the opportunity costs of fuelwood collection. Additionally, agricultural specialization, particularly concentrated livestock operations (such as a small number of large-scale pig farms substituting for traditional pig-raising by every rural household), also reduces energy consumption in cooking livestock fodder for rural households. Meanwhile, large-scale livestock facilities use more current technology and management practices with different feeds and utilize less energy for cooking.

With the cross-over to alternative fuel sources, forests in the mountainous and hilly regions recover much better than before as

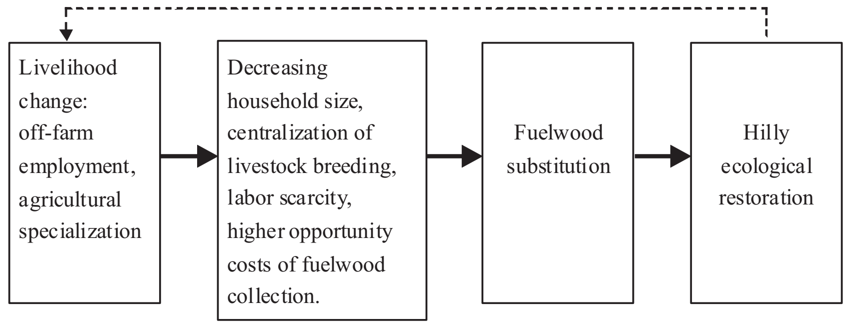


Fig. 1. Conceptual framework of rural livelihood change and fuelwood substitution.

they are less disturbed by fuelwood collection. As hilly ecosystems are restored, biomass and vegetation productivity are increased, creating positive feedback on agricultural specialization (indicated with a dashed line in Fig. 1) such as the development of large-scale orchards. In sum, hilly ecological restoration in some ecologically fragile regions is encouraged by the progressive changes of household livelihoods (Fig. 1).

2.2. Study area

Changting County is located in western Fujian Province of Southeast China (25°18′40″ to 26°02′05″N, 116°00′45″ to 116°39′20″E) (Fig. 2), and situated on the southern part of WuYi Mountain. Changting is characterized by a humid, subtropical monsoon climate with high mean precipitation (1730.4 mm yr^{-1}) and warm annual temperatures (a mean of 18.3 °C and a minimum temperature of 7.9 °C) [51], and it is primarily covered by granite red soils. Historically, it was covered by luxuriant vegetation with light soil erosion. However, a half-century period of forest deforestation, primarily resulted from heavy fuelwood collection, has significantly reduced vegetation coverage and caused severe soil erosion in many mountainous and hilly regions [17].

Changting County consists of 18 towns and 290 administration villages, with a total land area of 3100 km^2. Changting County was well known as one of the most poverty-stricken counties of China due to poor transportation, mountainous topography, a fast-growing population and scarcity in natural resources (about 0.042 ha arable land per capita in 2008). In spite of fast growth in recent years, in 2008 the GDP per capita was still only RMB 12,892 (about 1896 US $), just about 43% of the average level in Fujian Province, and the net income per farmer was only RMB 4910 (about 722 US $), about 80% of average provincial income. Therefore, Changting County is still an underdeveloped county within Fujian Province.

Since the 1980s, the gap between local poverty and rapid economic growth of coastal areas has generated a large movement toward coastal migration. Moreover, as local urbanization grew rapidly in recent years, many farmers transformed into local manufacturing and construction workers [17]. In 2008, off-farm laborers in rural areas of Changting County amounted to 160 thousand, accounting for 58.61% of total rural labors (Agriculture Bureau of Changting County, 2010). Crop and livestock production are the major agricultural activities for most rural households within Changting County. Traditional subsistence agriculture has been the typical feature of rural areas, with each household cultivating a small amount of cropland. Nevertheless, over time, more cropland has been transferred and concentrated into fewer farmers. In 2010, 31.58% of cropland in Changting County was transferred, and 78.71% of this cropland was shifted to households specializing in agricultural production or to agricultural cooperatives utilizing large-scale management. Due to poverty and energy scarcity, biomass fuel, mainly fuelwood, is historically the principal cooking energy for rural households in Changting County. Fuelwood collection, such as harvesting of trees and woody vegetation was an indispensable part of most farmers' livelihood activity before 1990. Under pressure from a rapidly increasing rural population, the exploitation of the remaining forest vegetation surpassed the degradation threshold of the hilly ecosystem, leading to severe forest degradation and soil erosion [17]. Only toward the end of 1990s as commercial energy such as coal, LPG, and electricity began to substitute for fuelwood as an energy source for cooking, did hilly ecological restoration take place [17].

2.3. Data collection

In order to examine the relationship between fuelwood substitution and the changes in rural household livelihoods, two kinds of data were collected: the socioeconomic data of Changing County, and a survey of 6 representative villages in 4 towns (Cewu, Hetian, Sanzhou, and Xinqiao) with distinct changes in livelihoods (Fig. 2).

All secondhand socioeconomic information of Changting County was collected from official data of related administrative departments such as the Bureau of Statistics, Agricultural Office, Bureau of Agriculture, Bureau of Forestry, Bureau of Water and Soil Conservation, and the Population and Family Planning Committee of Changting County. These data mainly include two parts: the two Agricultural Surveys of China, performed by Changting County Bureau of Statistics in 1996 and 2006; and Changting County Statistics Yearbooks, Statistics Bulletin of the Economic and Social Development of the Changting County, Statistics Bulletin of the Ecological Treatment of the Changting County. All prices have been converted to real prices for comparability. The key leaders of these administrative sectors were interviewed to enhance our overall understanding of the real conditions [17].

The survey data were collected from January 15, 2010 to August 28, 2010. Once the villages were selected, households were selected by random sampling. The sampling proportion is about 10% of total village households. In all, 380 farming households in 6 villages were selected. Each household was asked to answer the questionnaire, which consisted of 45 questions in 4 parts: basic information, livelihood situation, energy consumption, environmental effects. Basic information mainly includes questions on household size, gender, age, occupation, educational level of the responding family head, landholdings, building conditions, production equipment and technologies (such as tractor), financial assets, social resources, net-income, and family expenditure. Livelihood situation mainly consists of questions on composition of household income, labor allocation among sectors, and future adjustment of livelihood strategies. Energy consumption contains composition, quantity, source and cost (price of fuels and labor utilized to obtain firewood) of energy for cooking used by the responding household during a one year period. Environmental effects consist of

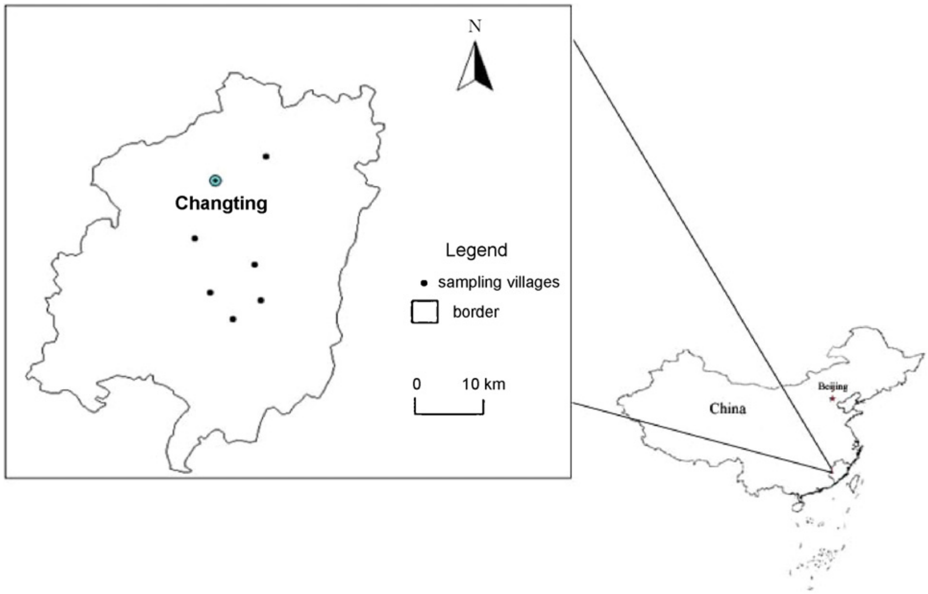


Fig. 2. The location of study site.

questions on the perception of impacts of fuelwood substitution on hilly ecosystems.

These questionnaires were conducted by our professional investigators through a question-and-answer format to ensure the accuracy of the survey. In rural households where it was difficult to isolate a respondent, a collective household interview was conducted [52]. The majority of questions were answered by the household head, and the other family members completed some questions. Follow-up interviews were conducted with select respondents in order to assure survey reliability and to provide explanations for unclear responses. After eliminating 22 invalid records, we had 358 effective respondents. The characteristics of these rural households are presented in Table 1.

Face to face interviews with village leaders or accountants were also carried out. Two leaders were chosen in each village. Open answers were designed for village-leader questions. Due to the relatively open structure of the interviews, new issues of particular interest to the respondents could arise during interviews according to a semi-structured methodology [53]. Through these interviews, information on rural socioeconomic evolution was collected, such as population and households, quantity of land, labor allocation between agriculture and off-farm employment, composition of average household income, specialized agriculture conditions, structure and costs of cooking energy, change of wages in off-farm employment, land use/land cover change over the past two decades, and environmental change [17]. In general, the primary aim of village leader interviews was to achieve a holistic understanding of changes in livelihoods, fuelwood substitution, and hilly ecosystem restoration.

3. Transition of rural household energy consumption

To better understand the mechanism and consequences of fuelwood substitution, it is vital to understand the transition of rural household energy consumption for cooking, feeding and heating, which are major components of fuelwood use. This study investigated the process of fuelwood substitution based on data from surveys of rural households in Changting County during different periods. Specific analysis is as follows:

3.1. Change in per capita energy consumption

All fuel types were converted to comparable units, kilograms of coal equivalent (kg ce), to evaluate the per capita energy consumption in Changting County in different phases. Overall, the per capita energy consumption for cooking, feeding and heating has shown a tendency of firstly rising, then decreasing trend (Fig. 3). In 1985, per capita energy consumption amounted to 292.34 kg ce, which was slightly less than the national average [54]. Since then it increased gradually, reaching a peak of 389.46 kg ce in 2006, but then decreasing to 330.88 kg ce in 2010 (Fig. 3). This seems contradictory with past literatures generally claiming an increasing trend of per capita energy consumption of rural households with rising household incomes [54–56]. The reason may lie in the fact that fuels for uses such as cooking, feeding, and heating was about half of total energy consumption in rural areas [57].

3.2. Change in energy consumption structure

From 1985 to 2010, an important change was reflected in the energy consumption structure which transferred from traditionally non-commercial fuels (mainly fuelwood and straw) to commercial and industrialized fuels such as coal, LPG, and electricity (Fig. 4). The non-commercial fuels for cooking, feeding and heating accounted

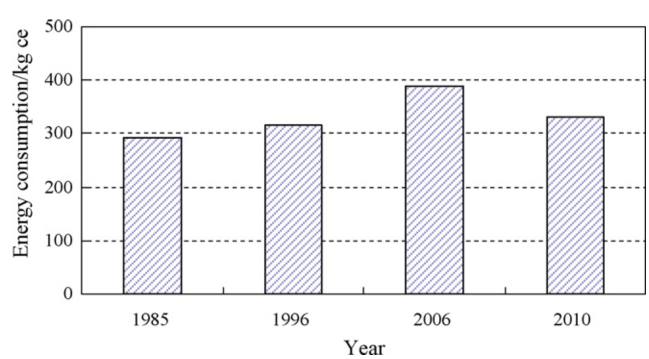


Fig. 3. Per capita energy consumption change of rural households in Changting County.

Table 1
Basic conditions of surveying villages in Changting County.

Village	Nantang	Luhu	Nanduan	Sanzhou	Nankeng	Xinqiao
Total households (household)	748	433	866	1016	263	1066
Total population (person)	3403	1832	3902	4036	1105	4444
Cropland (ha)	128.93	82.80	138.20	215.60	51.47	108.93
Forestland (ha)	415.40	840.27	2511.80	449.73	700.67	727.60
Sample size (household)	62	37	70	82	21	86
Sample households of total (%)	8.29	8.55	8.08	8.07	7.98	8.07
Migrating labors of total (%)	38.96	55.02	54.02	45.14	60.00	58.42
Specialized agriculture	Paddy	Vegetables, chestnut	Tobacco	Waxberry	Ginkgo, pig-raising	Vegetables

Source: Statistical Bureau of Changting County; Our fieldwork.

for 83% of energy consumption in 1985, but only 12.85% in 2010. Therefore, the most apparent trend in rural energy consumption is biomass energy being replaced by commercial fuels in Changting County.

4. Environmental impacts of rural energy transition

As the historically dominant energy source in rural areas, fuelwood collection has often been the key driver of wood consumption. From the 1960s to 1980s, collecting vegetation and wood from forestlands for cooking fuel led to a sharp decrease in forest vegetation rates and severe soil erosion in Changting County. The size of the area experiencing serious erosion increased by 5.1% annually, from 478.70 km^2 in 1966 to 974.79 km^2 in 1985 [51]. However, overall soil erosion overall was reduced from 1985 to 1995, due to rapid energy transition from fuelwood to commercial fuels. The area experiencing serious erosion was reduced by 23.32%, from 747.33 km^2 in 1985 to 434.50 km^2 in 1995. But it must be pointed out that severe soil erosion (>8000 $t\,km^{-2}\,yr^{-1}$) increased 56.29 km^2 owing to massive forestland exploitation during the same period (see Table 2).

Remarkably, great improvements have been made to the health of the ecosystem since the late 1990s. Vegetation and forest coverage increased by 19.50% and 13% respectively from 1995 to 2007, mainly due to less destructive human disturbance. The improvement in forest and vegetation cover further mitigated soil erosion. Soil erosion decreased greatly during the same period. The total area of soil erosion declined by 41.86% and the area of land experiencing heavy soil erosion (5000–8000 $t\,km^{-2}\,yr^{-1}$) decreased by 41.52%. The improvement revealed the substantial ecological restoration brought about by alternative sources of energy substituted for fuelwood in rural areas.

5. Linking fuelwood substitution with rural livelihood change

Fuelwood substitution in rural areas is closely related to changes in household livelihoods.

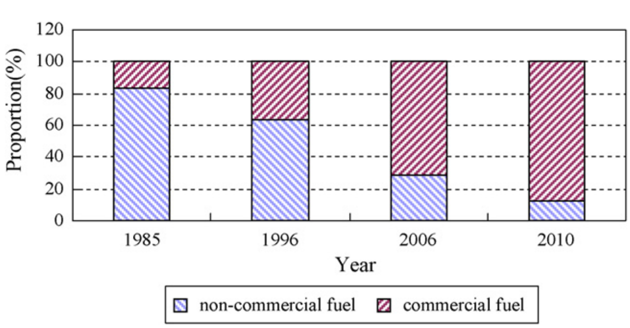


Fig. 4. Fuel consumption structure change in rural households of Changting County.

5.1. The rural depopulation due to outmigration

Due primarily to large scale rural–urban migration, Changting County has experienced a drastic decrease in rural population. The number of rural laborers migrating to urban areas increased from 59.86 thousand in 1996 to 89.63 thousand in 2006 (Agricultural Survey of China in 2006). Besides the temporary rural–urban migrating labor force, many rural households have moved to urban areas and settled down permanently, completely converting into urban households with local registration (*hukou*). During the same period, it was estimated that about 84.10 thousand rural residents transformed into urban residents. As a result, the density of rural resident population decreased by 34.42% (from 127 persons/km^2 in 1996 to 83 persons/km^2 in 2006).

Rural depopulation implies fewer consumers of energy, as well as laborers to collect fuelwood. The number of household members who resided in rural areas decreased from 4.48 persons in 1996 to 3.42 persons in 2010, a reduction of 23.66%. Thus the sharp decline of energy consumers in rural areas could adjust the relationship between fuelwood demand and supply, substantially mitigating the pressure of human population on the fragile upland ecosystem. The labor scarcity induced by outmigration had a great impact on rural fuelwood consumption since the young and middle-aged agricultural labors could exert the highest impact on the forestland. The remaining members were generally children and elders who have a smaller influence on the hilly ecosystem.

5.2. Opportunity costs of fuelwood collection

Rural households are traditionally self-sufficient in fuelwood. Fuelwood trade was not active. However, each household determined the energy source by comparing the costs. The productivity of labor in fuelwood collection vis-à-vis the opportunity costs of time in alternative employment plays an important role [5]. The opportunity costs of fuelwood collection are reflected in the rural wage rate. The average opportunity costs of fuelwood collection have been increasing (Table 3).

Due to the rapidly increasing wage rate for rural laborers and growing off-farm opportunities, the opportunity costs of collecting fuelwood have been increased substantially since 1995. The wage of a common rural labor increased from RMB 1.3 in 1995 to 36 in 2010, growing by 27.69 times. Meanwhile, the price of coal, which is nowadays the most important alternative energy source, rose from RMB 0.04 per briquette to RMB 0.65 per briquette, and increase of 16.25 times. The growth rate of coal price was remarkably slower than that of related opportunity costs of fuelwood collection (Table 3). The quantity of fuelwood collected by one middle-aged rural laborer in a day can meet five days of energy consumption. As a result, the opportunity costs of fuelwood collection make it a non-viable energy source for most rural households.

Table 2
The changes in vegetation cover, forest cover, and soil erosion in Changting County.

	1985	1995	2007
Vegetation cover (%)	64	62	81.5
Forestry cover (%)	65	63	76
Area in which soil erosion was occurring (km^2)	974.79	747.33	434.50
(1) Light soil erosion (<2500 $t\ km^{-2}\ yr^{-1}$) (km^2)	594.73	483.32	245.00
(2) Moderate soil erosion (2500–5000 $t\ km^{-2}\ yr^{-1}$) (km^2)	207.13	58.21	123.60
(3) Heavy soil erosion (5000–8000 $t\ km^{-2}\ yr^{-1}$) (km^2)	117.13	93.71	54.80
(4) Severe soil erosion (>8000 $t\ km^{-2}\ yr^{-1}$) (km^2)	55.80	112.09	11.30

Source: Water and Soil Conservation Bureau of Changting County.

Table 3
The change of opportunity costs of fuelwood collection in Changting County.

Year	Rural labor wage (RMB/day)	Rural employment opportunity rate[b] (%)	Opportunity costs (RMB/day)	Five-day coal costs[c] (RMB)
1995	13	10	1.3	1
2000	17	40	6.8	4
2005	30	60	18	8.75
2010	45[a]	80	36	16.25

Source: Own fieldwork.
[a] RMB 1 Yuan = 0.15 US $.
[b] Rural employment opportunity rate is gained by practical working days/willingly hired days in a year for long-term surveyed households.
[c] Supposing a family of four consumed five briquettes for cooking each day only using coal.

Table 4
Per capita energy consumption of different rural households in Changting County.

	Annual energy consumption per capita*** (kg/ce)	Number of resident member** (person/household)	Feeding pig number*** (no./household)	Off-farm income of total*** (%)	Net income per farmer*** (RMB)
PFH	492	3.32	10.6	1.84	3240
MFH(type I)	350	3.94	2.47	31.67	4500
MFH(type II)	293	3.85	1.62	73.77	4814
NH	303	3.06	0.3	97.43	6570
Average	330.88	3.42	2.31	71.22	5418

Source: Our fieldwork.
Note: PFH, pure farmer household; MFH(type I), mixed farm-business household(type I); MFH(type II), mixed farm-business household(type II); NH, nonfarm household.
** Significant at 5% level.
*** Significant at 1% level.

5.3. Transformation of rural agriculture

The process of agricultural transformation also facilitated a shift in family economic activities from subsistence oriented monoculture food production systems to modern agricultural systems [49]. According to our survey in 2010, average arable land per household was about 0.19 ha. However, a household that specializes in farming usually cultivates more than 0.67 ha, about 3.5 times more than a traditional, self-subsistence household. A specialized pig-raising household usually has 80 pigs, while a traditional household only has 2 pigs.

Specialization in agricultural production leads agricultural activities to concentrate among fewer households. A majority of the labor force changes into non-farm employment. As shown in Table 4, the number of pigs each household raised and the household size all exhibit a declining trend with the increase of off-farm income ratio, together leading to a decline in the energy requirement per household. The change of raising pigs becomes more concentrated in some large farms also results in rapid decrease in cooking energy consumption per capita. This is because the energy used in raising a pig using the traditional method of cooked feeding is somewhat higher than the energy consumed in cooking for a person [58]. Large-scale pig farms often use different foods with less cooking. Thus the transition from courtyard pig-feeding by every household to specialized pig farming boosts the energy savings.

It was found that households with a higher non-farm income ratio usually have higher household net income, which was considered to promote the energy transition from fuelwood to commercial energy. As shown in Table 4, the net income per farmer of NH is tremendously higher than that of others. In addition, specialized farmers with large-scale management generally have higher household incomes, the average net income per farmer amounting to RMB 9436, being 1.7 times of the average value of surveying 358 households. Thus, agricultural specialization facilitates the substitution of fuelwood to some extent through the income effect.

6. Discussion and conclusions

Fuelwood is still an important household energy source in rural hilly and mountainous regions of China [1]. Fuelwood extraction not only costs a lot of time but also causes severe forest degradation and soil erosion in environmentally fragile regions. Fortunately, the rapid energy transition from fuelwood to commercial fuels in rural China is taking place. Existing literature addresses the driving forces of rural fuelwood substitution primarily from household income, energy availability and accessibility, family size, householder education level, livestock feeding, technology customization and innovative financing [1,22,59–66], but neglects the impact of changes in the livelihoods of rural households. This paper seeks to contribute to current knowledge by including this vital factor in analyzing the transition away from fuelwood.

Using Changting County as example, this study demonstrates the transition away from traditional biomass energy and toward commercial energy sources in China. Per capita energy consumption and energy structure, particularly for cooking and pig raising,

were addressed. A steady decline in per capita fuelwood consumption has been found in rural areas of Changting County.

The relationship between fuelwood collection and the health of forest ecosystems is more complicated than normally acknowledged. Most literature focuses on the relationship between excessive fuelwood collection and forest degradation in developing countries [66–70]. However, less attention has been paid to the effects of fuelwood substitution in developing countries. Our results indicate that transition away from fuelwood energy sources in rural areas could lead to substantial restoration of hilly ecosystems, reflected in improvement of vegetative coverage and soil erosion. This is consistent with experience of forest transition primarily found in developed countries [18,71,72].

As for the driving forces behind fuelwood substitution, changes in the livelihoods of rural households are found to be the primary force, leading to changes in household characteristics which include not only household size, gender composition, education, and age, but also number of animals and the raising methods. The income change from traditional subsistence agriculture to off-farm employment and agricultural specialization stimulates rural households to shift away from fuelwood toward commercial energy sources.

Increasing off-farm employment leads to a decline in resident household size, and the withdrawal from traditional courtyard livestock raising method. It must be pointed out that the change in household size is different from some researchers [73], who examined the change in household size from other aspects such as divorce, marriage and mortality.

From this study, some policy implications can be made. As the rising opportunity costs of fuelwood collection are the most important factor, effectively regulating fuelwood collection from open access forests and commons would encourage most rural households to actively and voluntarily substitute fuelwood [74].

At all levels, China's governments have carried out large-scale afforestation, and have imposed coercive measures on local populations, such as closing hillsides to facilitate afforestation, but the function of changes in rural household livelihoods has not been adequately realized. Because off-farm employment and agricultural specialization are important factors in fuelwood substitution, government should devote more effort to the improvement of rural household livelihoods. This can be done through a series of measures including increasing the off-farm employment opportunities through *in situ* urbanization and labor export [75], developing labor mastery of a skill or technique by government-sponsored training, propelling the development of cropland transfer and agricultural specialization, and supplying social relief for the poverty-stricken rural households. These policies could have positive effects on energy transition and ecological restoration in rural areas of China and be helpful in promoting coordinated development of coupled human and natural systems.

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